Radar Echo Enhancement Using Surface Reflections

BEN H. CANTRELL

Radar Analysis Branch
Radar Division

September 28, 1984

DTIC
ELECTE
OCT 3 1 1984

B

84 10 30 095

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b RESTRICTIVE MARKINGS			
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited.			
2b DECLASSIFICATION / DOWNGRADING SCHEDULE					
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Report 8849		5 MONITORING ORGANIZATION REPORT NUMBER(S)			
6a NAME OF PERFORMING ORGANIZATION Naval Research Laboratory	6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION			
6c ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000		7b ADDRESS (City, State, and ZIP Code)			
8a NAME OF FUNDING/SPONSORING ORGANIZATION Office of Naval Research	8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			

8c ADDRESS (City, State, and ZIP Code) Arlington, VA 22217	10 SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO 61153N	PROJECT NO 021-05-43	TASK NO. 53	WORK UNIT ACCESSION NO. DN480-006

11 TITLE (Include Security Classification)

Radar Echo Enhancement Using Surface Reflections

12 PERSONAL AUTHOR(S)
Cantrell, Ben H.

13a TYPE OF REPORT Interim	13b TIME COVERED FROM _____ TO _____	14 DATE OF REPORT (Year, Month, Day) 1984 September 28	15 PAGE COUNT 11

16 SUPPLEMENTARY NOTATION

17	COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Detection Multipath
			Radar signal processing Radar

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Analysis and simulation have shown that the detection of targets by pencil-beam radars could be enhanced by using strong surface reflections which are sometimes present. The radar used a beam pointed at the target and a beam pointed at the target reflection on the surface. Transmitting only on the direct beam and simultaneously receiving the direct and reflected beam energy, up to 2.5 dB improvement in signal-to-noise ratio (S/N) was obtained. During strong reflecting conditions, transmitting and receiving simultaneously over both beams made up to 5.5 dB improvement in S/Ns, but the improvement and occasional loss depended heavily on the target location within the beam.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a NAME OF RESPONSIBLE INDIVIDUAL M.I. Skolnik	22b TELEPHONE (Include Area Code) (202) 767-2936	22c OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

CONTENTS

DTIC
ELECTE
OCT 3 1 1984

B

RADAR ECHO ENHANCEMENT USING SURFACE REFLECTIONS

INTRODUCTION

Current fan-beam radars located on ships exhibit variation in signal strength and have a significant increase in target signal strength at some angles when the surface reflections in front of the radar are strong as described in Section 2.6 of Ref. 1. Pencil-beam radars, except for the surface beam, do not exhibit this strong variation in signal strength across the beam. Although the radiated signal energy reaches the target and the target echoes reach the antenna through the surface reflections in the pencil-beam radars, the surface-reflected signal is weak because it enters via the low antenna sidelobes. The subject of this study is to consider a system and its performance which uses the strong surface reflections to enhance target detections in pencil-beam radars. Some other studies [2-5] use the surface reflection to enhance target detection.

Consider a pencil-beam radar pointing at a high-elevation target. The target echo returns along the direct path and also reflects from the surface. If a pencil beam is pointed down toward the reflecting surface, the surface-reflected energy can be captured as well and can have almost the same signal-to-noise ratio as the original, upward-pointed direct beam; for good reflecting conditions, nearly a 3 dB enhancement in signal energy is expected. We will analyze radar systems which use pencil beams pointed toward the target and its surface reflections. We begin by defining a radar geometry and an associated set of interference patterns caused by the interfering electromagnetic waves. We then define the receiver noise and signal processing used. Finally, the detection performance is compared to a standard system that uses a pencil beam pointed at the target.

RADAR GEOMETRY

A radar using two beams is situated above a flat reflecting surface as shown in Fig. 1. One beam is pointed at the target and one is pointed at the reflecting surface so its reflection is pointed at the target. The angle at which the reflected beam needs to be pointed is given by

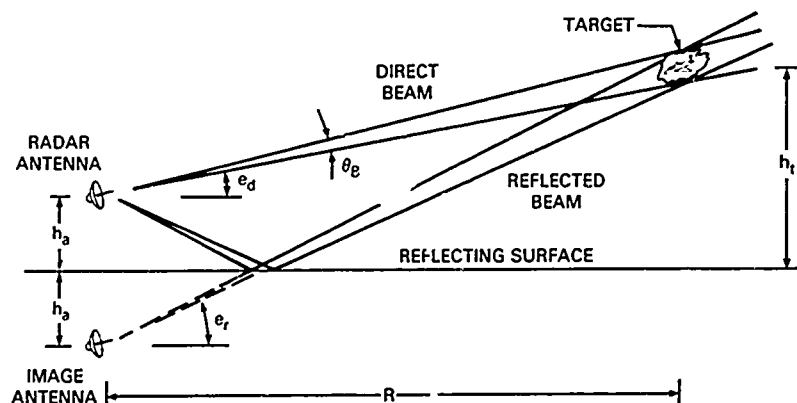$$e_r = \tan^{-1}\left[(\tan e_d) + \frac{2h_a}{R}\right],$$

Fig. 1 — Geometry of radar antenna and target

where

e_r is the reflected beam pointing angle,

e_d is the direct beam pointing angle,

h_a is the antenna height, and

R is the ground range between radar and target.

The difference between e_r and e_d is plotted versus range in Fig. 2 for $h_a = 50$ ft. We can determine two things from the curve. First, we note that the aspect angle at which the beams view the target is nearly the same, making the target cross section under bistatic scattering essentially the same as monostatic scattering for typical targets. Secondly, we see that if we set R equal to infinity, then $e_r = e_d$. If we always use this value of the pointing angle, $e_r = e_d$ for the reflected beam, Fig. 2 shows the error in alignment of the center of the two beams on the target. With little error then, we can use the monostatic radar cross section and, too, not have to worry about small errors caused by pointing of the beams.
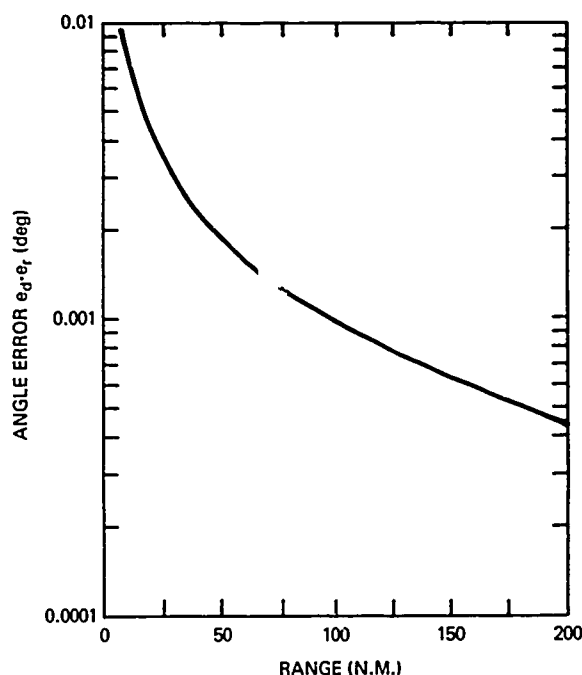

Fig. 2 — Aspect angle difference between direct and reflected
beams as a function of range for $h_a = 50$ft and e_d below 10°

INTERFERENCE PATTERNS

The reflecting surface, such as the sea or a grassland, in front of the radar is not flat, but we can approximately describe it with a complex reflection coefficient ρ and set the angle of reflection equal to the angle of incidence.

We transmit first on the direct so there is a plane wave sweeping over the target. The target equally reflects a signal along the direct and reflected paths. The phase difference ϕ along the antenna aperture between the reflected and direct signals is given by

$$\phi = \frac{2\pi}{\lambda} 2(h_a + x) \sin e_d + \psi \tag{1}$$

2

where λ is the wavelength, x is the vertical location along the aperture and varies from $-d/2$ to $d/2$, ψ is the phase shift due to the reflecting surface, and d is the vertical aperture width. The plane wave from the sinusodially excited direct path has a root-mean-square (rms) electric field strength E_d, and from the reflected path of $|\rho| E_d$. We plot the rms field strength across the aperture

$$E_a = \sqrt{2} \, E_d \, F \tag{2}$$

where

$$F = \sqrt{(1 + |\rho| \cos \phi)^2 + (|\rho| \sin \phi)^2} / \sqrt{2}$$

in Fig. 3 for $|\rho| = 1$, $d = 10 \, \lambda$, $h_a = 55\lambda$, $\psi = 180°$, and $e_d = 25°$. We find there are nulls and peaks across the aperture and note that the average rms power level across the aperture is 3 dB higher than if only the direct plane wave were present. It can also be shown by using Eqs. (1) and (2) that as e_d decreases or the antenna width is narrowed (a .n 2D radars), there is only one lobe or null across the antenna. Thus, at low elevations, the average rms power level can be 6 dB higher at times and negligible at other times.

Fig. 3 — Electric field strength across vertical dimension of aperture for $d = 10\lambda$, $h_a = 55\lambda$, $e_d = 25°$, and $|\rho| = 1$
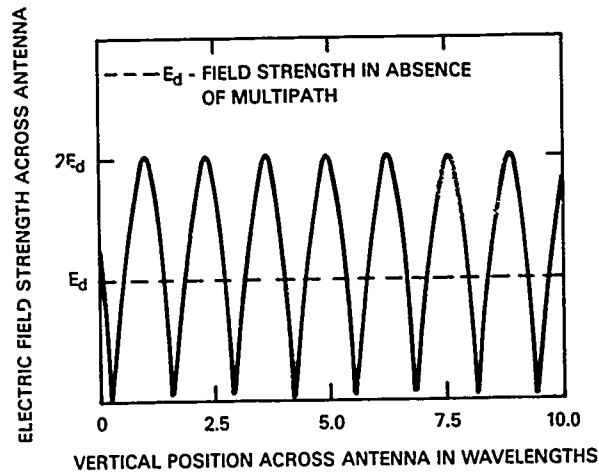
If the same total power is divided equally and a sinusoid signal is transmitted over both the direct and reflected beam channels, an interference pattern is set up in space. In fact, Eqs. (1) and (2) also describe the electric field in elevation across the beam. An example is shown in Fig. 4. We find that for at least the longer range targets, the power density is nearly uniform across the target, i.e., the target angle extent is small compared to distance between lobes. For unity reflection coefficients, the power density on target can be twice that of the single beam at some elevations and zero at other elevations. Note that the power density would be 6 dB above that of a single beam if the power were not split between the beams. This 6 dB improvement occurs naturally in fan-beam radars.

RECEIVER NOISE

The noise level in each channel is composed of receiver noise and external noise. The external noise in the direct beam at the higher elevations is quite low at microwave frequencies. The beam pointed into the ocean has a noise level bounded between the reflection of the sky noise (equal in power to that of the direct beam) and approximately 290 K. The external noise in the reflected beam depends on the reflecting properties of the earth, the surface roughness, polarization, grazing angle, etc.; a rough guess might be a noise temperature of 100 to 150 K for typical conditions. If we use a 5 to 6 dB noise figure receiver, the external noise in both beams is practically negligible. For our analysis, we assume the noise power in each channel is equal, and that the noise signals are Gaussian-distributed, zero mean, and uncorrelated.
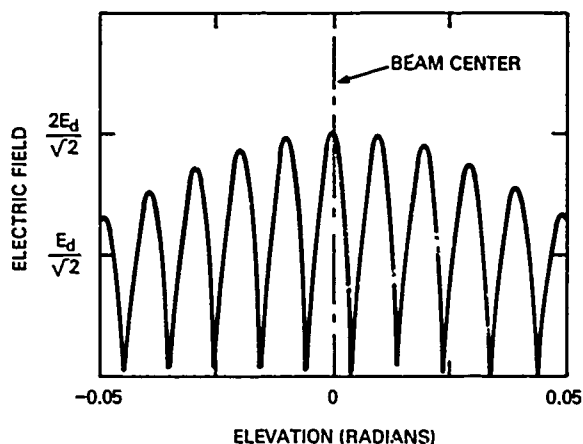
Fig. 4 — Electric field strength across beam at far range for $d = 10\lambda$, $h_a = 55\lambda$, $e_d = 25°$, and $|\rho| = 1$

It may be useful to have a low-noise receiver in the reflected beam channel and use it as a radiometer. By monitoring the external noise level in the reflected beam, we might be able to determine the reflection coefficient of the sea [6]. This may help in learning how to use this system.

SIGNAL PROCESSING

The baseband signals sampled at the range of the target can be represented by the complex numbers Y_d and Y_r. The signals are composed of target signal and noise, i.e.,

$$Y_d = S_d + N_d$$

$$Y_r = S_r + N_r$$

where S_d and S_r are the signal levels from the direct and reflected paths, and N_d and N_r are zero mean, Gaussian-distributed uncorrelated noise of power σ^2. The direct and reflected signal levels are computed from

$$S_d = S F$$

$$S_r = \rho S F$$

where S is the complex signal that would be present if only a single direct transmit beam were used, and ρ is the complex reflection coefficient. For transmission on the direct beam only

$$F = 1,$$

and for transmission on both beams

$$F = \sqrt{(1 + |\rho| \cos \phi)^2 + (|\rho| \sin \phi)^2}/\sqrt{2}$$

as previously defined in Eq. (2). The signal-to-noise ratio is defined by

$$(S/N) = \frac{|S|^2}{2\sigma^2} .$$

For purposes of comparison, a nonfluctuating signal was used.

The detectors compute either

$$Z_1 = |Y_d|^2$$

for a reference system using the direct beam only, or

$$Z_2 = |Y_d|^2 + |Y_r|^2$$

4

using both the direct beam and reflected beam. We combine the signals noncoherently since we do not know the relative phase. Using the Neyman-Pearson detection criteria, we set thresholds with Ref. 7 to yield a probability of false alarm of 10^{-6}. Simulation gives the probability of detection P_d.

DETECTION RESULTS

The probability of detection for a probability of false alarm of 10^{-6} is shown as a function of signal-to-noise ratio for three different situations in Figs. 5, 6, and 7. All three figures show a reference case which is the normal case of transmission and reception using the direct beam only. The reference case can be found in Sec. 2.4 of Ref. [1]. Figure 5 shows the results for transmission on the direct beam, simultaneously receiving on the direct and reflected beam channels, and noncoherently adding the results. We found the probability of detection was independent of the phase difference between the two channels. Also, we got a 2.5 dB improvement in signal-to-noise ratio when the reflection coefficient was unity. We lost one-half of a dB from the 3 dB increase in energy due to non-coherently adding the signals. We also found that when the signal level in the reflected beam channel goes to zero, i.e., $|\rho| = 0$, we lost about .5 dB from the reference due to the added noise.
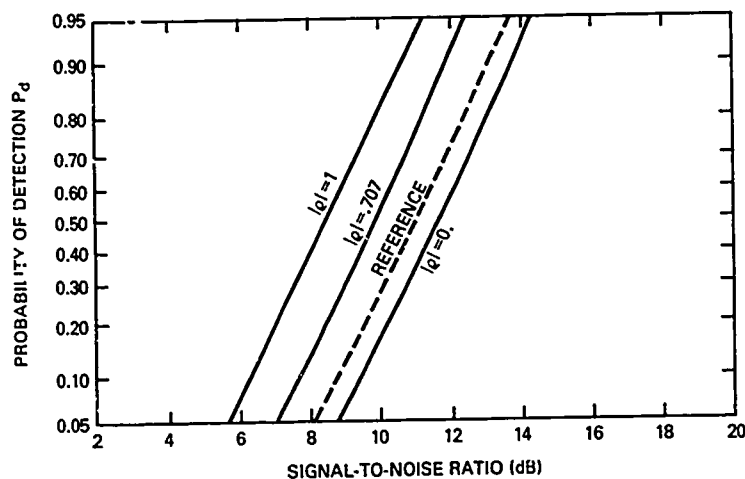

Fig. 5 — Probability of detection versus signal-to-noise ratio for a probability of false alarm of 10^{-6} using transmission on the direct beam only and reception using both the direct and reflected beam
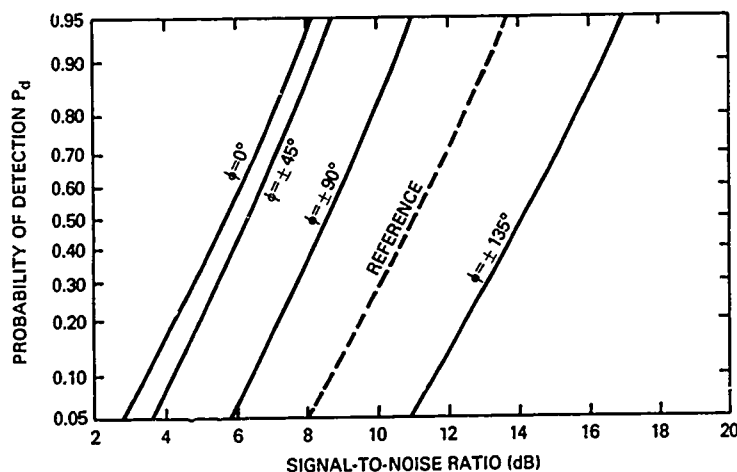

Fig. 6 — Probability of detection versus signal-to-noise ratio for a probability of false alarm of 10^{-6} using both the direct and relfected beams on transmission and reception for $|\rho| = 1$
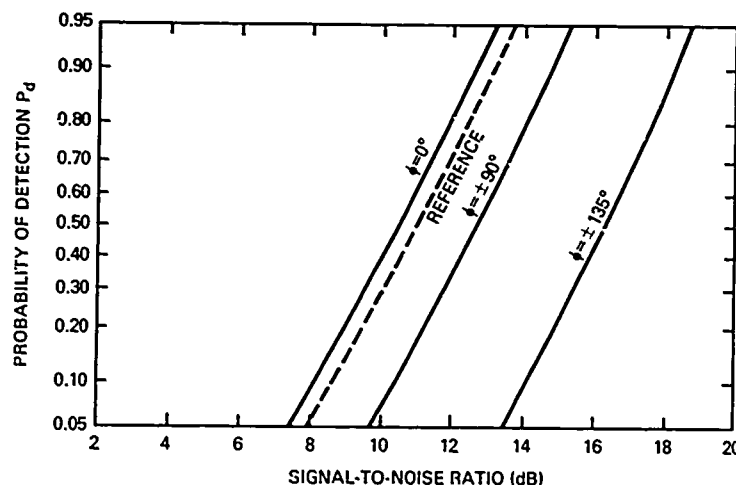
5

Fig. 7 — Probability of detection versus signal-to-noise ratio for a probability of false alarm of 10^{-6} using both the direct and reflected beams on transmission and reception where $|\rho| = 0.5$

The results of transmitting and receiving simultaneously on both the direct and reflected channels are shown in Figs. 6 and 7 for $|\rho| = 1$ and $|\rho| = 0.5$. We note first that although the processed received signals are independent of relative phase between the channels, the phase difference between the transmitted signals reaching the target is very important. Recall that the signal strength impinging on the target depended heavily on the target location in the beam and was caused by the relative phase of the waves in the two transmitted beams. As shown in Fig. 6, we find a 5.5 dB improvement in signal-to-noise ratio when the target location is such that the signals add in phase, i.e., $\phi = 0°$ and $|\rho| = 1$. The improvement is composed of 2.5 dB from reception (previously discussed) and 3 dB due to transmission. For all the other phases, there exists the 2.5 dB improvement due to reception. So, for $\phi = 90°$, there is essentially no improvement in signal-to-noise ratio due to transmission. And in Fig. 6 $|\rho| = 1$, we find that some targets in the beam can be enhanced considerably whil others located near the nulls of the lobing pattern can even take losses. The losses occur because the two signals arriving at the target nearly cancel themselves out.

In Fig. 7, we find that for $|\rho| = 0.5$, losses happen mostly when transmitting and receiving simultaneously on both channels because the power is split and energy lost in the direct beam. The energy from the reflected beam is even lower because of the low reflectivity; regardless of phase, the energy reaching the target is low. Where $|\rho| = 1$ in Fig. 6, we did not lose energy, we simply redistributed it. So, we conclude that we should not split the power and transmit along the two different paths unless we are certain the reflection coefficient is high.

SUMMARY

A radar system was defined for using the strong surface reflections to improve target detections in pencil-beam radars for those targets located about a half-beam width above the horizon. This system used an additional beam called the reflected beam as well as the original direct beam. The direct beam was pointed at the target and the reflected beam was pointed at the target reflection on the reflecting surface.

By transmitting only on the direct beam channel, and receiving on both the direct and reflected beam channels, we improved the signal-to-noise ratio unless the surface reflections were very weak. A perfect reflecting surface showed the best signal-to-noise ratio improvement of 2.5 dB, and a loss of 0.5 dB occurred for a perfect absorbing surface. It seems this technique can often yield an improvement in performance.

6

When the power was split and transmitted over both the direct and reflected beam channels, we did not get nearly as good results: a low reflection coefficient caused a loss of energy. We suggested, however, that the magnitude of the reflection coefficient might be estimated using radiometry techniques by inserting a low-noise receiver in the reflected beam channel. If the magnitude of the reflection coefficient can be estimated, and we transmit one half the energy over the reflected beam when the magnitude of the reflection coefficient is high, then nearly 6 dB improvement in signal-to-noise ratio can be had for some target elevation angles in the beam at the expense of losses at other target elevations. There may be times when one wishes to take these risks and choose such an option.

REFERENCES

1. M.I. Skolnik, ed. *Radar Handbook* (McGraw-Hill Co., New York, 1970).

2. B.H. Cantrell and B.L. Lewis, "Angle Detection of Small Objects," Patent Application, Naval Research Laboratory, Washington, D.C., July 1974.

3. B.H. Cantrell and B.L. Lewis, "Detection Improvement in Multipath Using Even and Odd Symmetric Antenna Patterns," NRL Memorandum Report 3301, May 1976.

4. B.L. Lewis, "Single Aperture Space Diversity Radar," Patent Application, Naval Research Laboratory, Washington, D.C., April 1980.

5. B.L. Lewis, "Adaptive Single Aperture Space Diversity Radar," Patent Application, Naval Research Laboratory, Washington, D.C., May 1980.

6. J.P. Hollinger, "Passive Microwave Measurements of Sea Surface Roughness," *IEEE Trans. Geoscience Electronics*, **GE-9** (3), 165-169, July 1971.

7. J. Pachares, "A Table of Bias Levels Useful in Radar Detection Problems," *IRE Trans. Information Theory*, **IT-4**, Mar. 1958, pp. 38-45.